Emergency Response Planning for Providing Drinking Water in Urban Areas after Natural Disasters using Multi Criteria Decision Making Methods

Bahram Malekmohammadi, Mehrdad Nazariha, Nikou Hesari

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Bahram MALEKMOHAMMADI*, Mehrdad NAZARIHA** and Nikou HESARI***

* Department of Civil Engineering, Islamic Azad University- Roudehen Branch, Tehran, Iran (E-mail: Malek471@yahoo.com, Malekb@ut.ac.ir)
** Faculty of Environment, University of Tehran, Tehran, Iran
*** Department of Civil, Environmental & Sustainable Engineering, Arizona State University

Abstract

The impact of a natural disaster can cause contamination of water, breaking pipelines, structural damages, water shortages, and collapse of the entire system. In emergency or disaster situations water supply are imperative for the rapid return to normalcy. In this paper, water supply planning for emergency response after natural disasters has been studied. Multi Criteria Decision Making (MCDM) has been used as a tool for incorporating decision maker preferences for water supply planning in emergency conditions. Analytical Hierarchy Process (AHP) as a well-known MCDM method was utilized for prioritizing water resources alternatives. For this purpose, the quality and quantity of water for living in emergency conditions after natural disasters were reviewed. Different water resources alternatives which are possible to use for emergency response were identified. Water resources availability, water quality, cost, affected population and delay in service were used as criteria for ranking the water resources alternatives. The proposed methodology was used for Pardis City in the vicinity of Tehran metropolitan in Iran, which is highly vulnerable to earthquakes and floods. The developed methodology provides an opportunity for further incorporation of decision makers' preferences in preparing an Emergency Response Plan (ERP) to improve respond to provide necessary water in disaster situation.

Keywords:

Water Supply; Natural Disasters; Multi Criteria Decision Making (MCDM), Emergency Response Plan (ERP); Pardis City, Iran.

INTRODUCTION

Drinking water is essential in ensuring the health and well-being of populations and plays an important role in the development process. All drinking water and sewerage systems are subject, to a greater or lesser degree, to natural disasters such as earthquakes, floods and droughts. The impacts of a natural disaster can cause contamination of water, break in pipelines, damage to structures, water shortages, and collapse of the entire system. In this situation, the main public health priority is usually to provide a basic water supply to the affected population (WHO, 1993).

Water utilities, regardless of their size and location, have a legal responsibility to provide clean, safe drinking water to their customers, even if supplying water under emergency conditions. In emergency or disaster situations these basic services are imperative for the rapid return to normalcy, so planning for emergency responding is really important. Planning for an emergency will not prevent the emergency from happening, but it will enable us to respond quickly and effectively (Manitoba Water Stewardship, 2009).

These characteristics of planning for drinking water in emergency show multi criteria decision making (MCDM) as an attractive approach. MCDM can be defined as a grouping of techniques for evaluating decision options against multiple criteria measured in different units (Voogd, 1983). A decision option is an action, or project, which contributes to the decision maker's objectives (Lago et al. 2006). Many researchers have found that MCDM provides an effective tool for water management especially in emergencies which needs proper response for prioritizing and choosing the best options for distributing and supplying drinking water. The purpose of this paper is to develop a methodology using one of the methods of MCDM which is Analytical Hierarchy Process (AHP) for choosing the appropriate alternative water supply and water ration in emergency situations.

MATERIAL & METHODS

In developing an emergency response planning (ERP) for water supplying the following steps are to be considered:

a) Estimating amount of adequate water quantity and quality in emergencies,

b) Exploring options for providing/increasing water supply in emergencies,

c) Prioritizing available alternatives based on the selected criteria by using MCDM tools,

d) Developing guidelines in order to use in disaster situation for water supply in affected areas.

Water quantity and quality in emergencies

The first priority in emergencies is to provide an adequate quantity of water to the affected population, even if its quality is poor, and to protect water resources from contamination. The human body's basic water requirements depend on the climate, workload and other environmental factors (UNHCR[1], 1992). In disastrous condition, a minimum of 15 liters per person day should be provided as soon as possible (The Sphere Project, 2004). Table 1 shows the minimum water requirements in disastrous condition.

Insufficient water and the consumption of contaminated water are usually the first and the main causes of ill health to the affect displaced populations during and after a disaster (WHO, 1998). Conventional bacteriological standards may be difficult to achieve in the immediate post-disaster period. The WHO guideline stated that zero E. coli per 100ml of water should be the goal and achievable even in emergencies, provided that chemical disinfection is employed (WHO, 1993). In reality, achieving the guideline standards may be difficult in some emergency situations, it is practical to classify water quality results according to the degree of health concern (Loyd, and Helmer, 1991, Delmas, and Courvallet, 1994). Table 2 shows the bacteriological guidelines in disastrous conditions.

[1] United Nations High Commissioner for Refugees (UNHCR)

Table 1: The minimum water requirements in disastrous condition (UNHCR, 1992)

Way of consumption	Total consumption (liters/person/day)
Personal consumption	15-20
Sanitation	40-60
Cooking	20-30

Table 2: Bacteriological guidelines for drinking water in disastrous conditions (Chalinder, 1994)

E. coli/100ml	Water quality
0-10	Reasonable
10-100	Polluted = Must chlorinate
100-1000	Very polluted
1000<	Grossly polluted

Options for providing/increasing water supply in emergencies

If a public water supply system is not capable of going back on line for an extended period of time, a long term alternate supply will be needed. It may be necessary for connection to an existing municipal or private water supply company; exploring for a new uncontaminated groundwater or surface water resource; and development of new water distribution system and storage facilities to compensate for loss of existing system capacity. These options assume the existing water treatment plant is intact and useable.

The emergency response plan should identify agencies or private companies that could provide water (bottled or bulk) in the occurrence of a major event. Provisions for bottled or bulk water should be established by mutual aid agreements with surrounding communities, industries, contractors and related utilities as appropriate. Points of contact for the alternate sources need to be updated routinely (Kansas Department of Health and Environment, 2005). Other potential sources for alternate water supplies include three types of approach (Chalinder, 1994):

A. Transporting water from existing sources to the population via piped systems or tankers,
B. Increasing the output/quality of existing sources by increasing pump and piping capacity, borehole/well deepening or treating surface water resources, using portable water treatment systems,
C. Creating new sources by drilling new boreholes or digging new wells.

Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) developed at the Wharton School of Business by Thomas Saaty. AHP allows decision makers to model a complex problem in a hierarchical structure which shows the relationships of the goal, objectives (criteria), sub-objectives, and alternatives (See Figure 1).

AHP is a systematic procedure for dealing with complex decision-making problems with many competing alternatives (projects, actions, and scenarios) (Saaty, 1990, Saaty and Vargas, 1994).

AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem. The hierarchy evaluation is based on pair wise comparisons (Anagnostopoulos, et al. 2003). In AHP, you can use verbal judgments in order to pair wise comparisons. The nine point's verbal scale for these judgments is used (Saaty and Vargas, 1994). If the number of decision makers is more than one person, it can be used Grouped AHP, in which decision maker's idea are used in calculating the important weights.

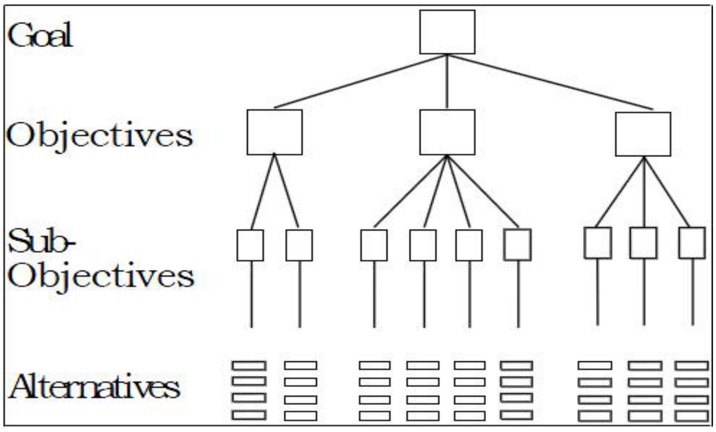

Figure 1: Decision Hierarchy

Case Study (Pardis City, Iran)

Pardis City in Iran is one of the satellite towns of Tehran metropolis, situated 25 kilometers in the east of Tehran of the both sides of Tehran-Mazandaran road. This city is highly vulnerable to natural disaster specially, earthquake and flood. The population of Pardis is about 50000 people. The total capacity of the water storage reservoir in Pardis is 26000 cubic meters and 2000 cubic meters for transferable reservoir. Daily consumption is 220 liter/ day per person. Pardis has 6 drinking water wells that three of them are beside Jajrood River (Hesari, 2011). Table 3 shows the available drinking water supply resources in this city. Table 4 shows information of drinking water system and in Table 5 data about constructed storage tanks in Pardis city are presented.

Table 3: Drinking water supply resources of Pardis City (Abran Consulting Company, 2008)

Well name	Well depth (m)	Discharge (Lit/s)
Well number 1	200	5
Well number 6	250	11
Damaghe Well	17	7
Wells beside Jajrood River	25	25

Table 4: Information of drinking water system in Pardis City (Abran Consulting Company, 2008)

Population of Pardis City	**Total Construction Cost** (Rial)	**Total length of water distribution system** (m)	**Water Requirement in Pardis** (lit/s)
50000	65512429160	57222	950

Table 5: Information of storage tanks in Pardis (Abran Consulting Company, 2008)

Number of covered people[1] (without loss in system)	**Total construction cost of tank** (Rial)	**Total volume of storage tanks** (m^3)
17333	2600000000	26000

RESULTS AND DISCUSSION

Criteria and Alternatives

In this paper, water supply and distribution options for Pardis city after natural disaster have been studied separately. The alternative options which are supposed for distributing water options are:

1. Pocket water
2. Water tankers
3. Portable water treatment system
4. Existent distribution system
5. Emergency tanks

The alternative options which are suggested for supplying water are:

1. Digging wells beside Jajrood River (Jajrood is a city close to Pardis and it has potential of water resources)
2. Digging hand wells
3. Existent storage tanks
4. Existent drinking water wells

Water management covers a wide range of activities, in which criteria such as technical, economic, environmental and time issues are involved. In this study, four criteria involve: water quality, cost, delay in service and number of covered people have been selected in prioritizing alternative options.

Loss scenarios

In this study, four hypothetical loss scenarios for water supplying and distribution alternatives are supposed separately. The evaluation model consists of four hypothetical loss scenarios on the future availability of water supply and distribution resources after natural disasters. These scenarios are described in the following and presented in Table 6.

[1] By supposing 15 liter water per person

1. Scenario one: Minor damages

These incidents are minor disruptions to the water system that affect 10% or less of the system and are anticipated to be repaired/resolved within 72 hours or less. Examples: Water main breaks and mechanical problems at pumping stations. It is supposed that in this scenario 90% of the system remain in operation.

2. Scenario two: Moderate damages

These incidents are more significant disruptions to the water system that affect 30% or less of the system and are anticipated to be repaired/resolved within 7 days or less. Examples: Local total coli form bacteria detection, major main breaks, multiple main breaks, major mechanical problems at pumping stations/treatment facility, or failure of chemical feed systems.

3. Scenario three: Extensive damages

These incidents are very significant disruptions to the water system that affect more than 50% of the system and/or are anticipated to require more than 7 days to be repaired/ resolved. Examples: break in major transmission main, loss or failure of treatment facility, loss of water resource (dam break, water supply shortage, contamination, etc.), loss of pressure in system, widespread total coli form bacteria outbreak, fecal coli form or E. Coli detection.

4. Scenario four: Total damages

These incidents are the most significant disruptions to the water system that affect approximately the whole system and/or are anticipated to require more than 7 days to be repaired/resolved (HAZUS, 2006). It is supposed that in this scenario the existed system will be out of operation.

Table 6 shows the information of three loss scenarios for Pardis City. This information helps the experts to have more accurate comparisons among alternative options for disaster situation.

Table 6: Hypothetical loss scenarios in disaster situation for water system in Pardis City

Loss Scenarios	**Percent of water system operation**	**Capacity of drinking water system** (lit/s)	**Volume of storage tanks**	**Well discharge** (lit/s)
Minor damage	90%	855	23400	20.7
Moderate damage	70%	665	18200	16.1
Extensive damage	50%	475	13000	11.5
Total damages	0	0	0	0

All of these information were available for experts for increasing the accuracy of judgments and pair wise comparisons. Experts use these tables for verbal judgments in order to fill the pair wise comparisons. In this paper, grouped AHP have been utilized in analyzing different alternatives. 29 experts from universities and organizations with different speciality were surveyed in gathering experts' opinions with questionnaires. For different scenario losses decision matrix were developed and incorporated in questionnaires. In summation, 32 matrixes are used in questionnaires for pair wise comparison between criteria and respected alternatives.

Hierarchy chart for prioritizing alternatives of water supply and distribution in disasters situation for Pardis City are presented in Figure 2. Criteria and alternatives important weights are calculated by Expert Choice software and presented in Tables 7 and 8. The more important weights show the more priorities for criteria and alternatives.

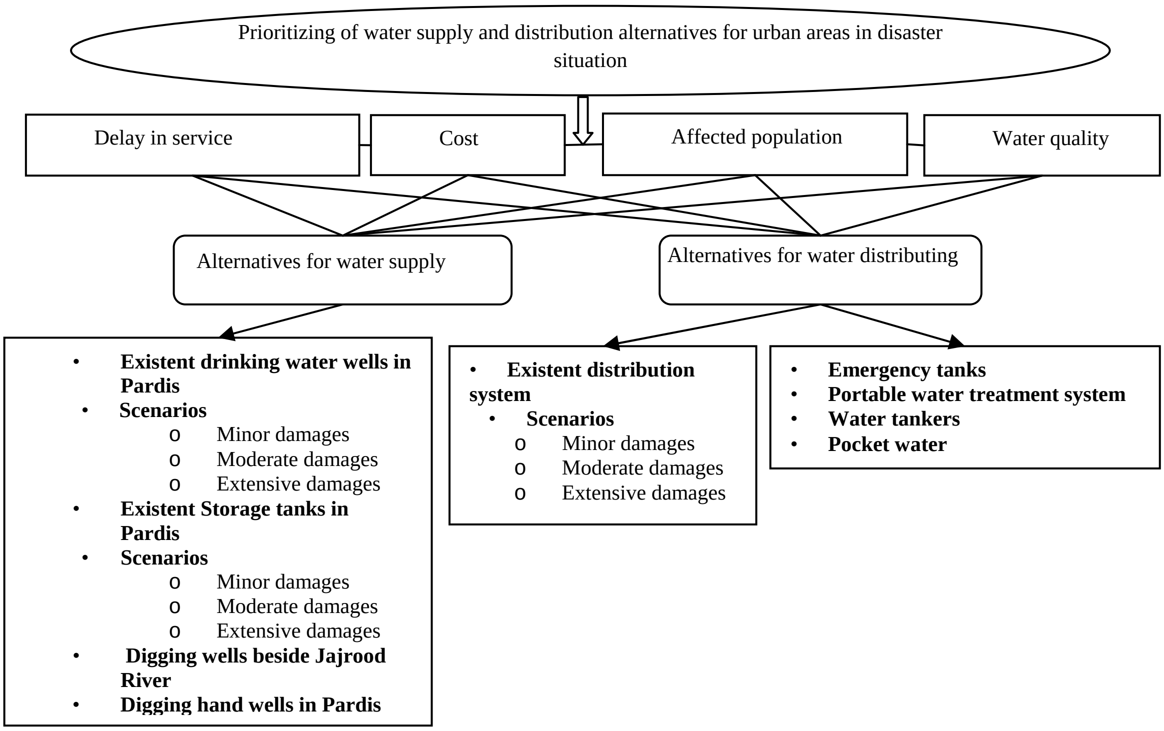

Figure 2- Hierarchy chart in prioritizing alternatives of water distribution and supply in disasters situation for Pardis City

Table 7: Important weights from pair wise comparison in grouped AHP for criteria

Criteria	Water quality	Affected population	Cost	Delay in service
Important weights	0.436	0.346	0.061	0.157

Table 8: Final important weights from pair wise comparison in grouped AHP for water distribution alternatives

Loss scenario / Alternatives	Minor damages	Moderate damages	Extensive damages	Complete damages
Emergency tanks	0.113	0.124	0.147	0.127
Portable water treatment system	0.230	0.273	0.357	0.392
Water tankers	0.125	0.153	0.183	0.172
Pocket water	0.257	0.268	0.28	0.308
Existent distribution system	0.276	0.181	0.034	-

Table 9: Final important weights from pair wise comparison in grouped AHP for water supply alternatives

Loss scenario / Alternatives	Minor damages	Moderate damages	Extensive damages	Complete damages
Existent drinking water wells	0.258	0.186	0.118	-
Existent Storage tanks	0.346	0.290	0.224	-
Digging wells	0.200	0.274	0.346	0.730
Digging hand wells	0.196	0.250	0.312	0.270

6. CONCLUSIONS

This paper discusses about prioritizing drinking water resources alternatives in order to plan for management in disastrous conditions. Firstly, to choose the best water resource for such conditions, a list of all available water resources must be provided. Secondly, potential for water supply and water ration have been prioritized in the affected area by identifying the best alternative water resources among available options. Here, water quality, cost, number of people, delay in services have been selected as default criteria for prioritizing the alternatives by using Multi Criteria Decision Making (MCDM) in different supposed loss scenarios.

In this study, four different hypothetic scenarios were defined and for each of the scenarios different options and criteria were evaluated by applying grouped AHP which is one of the well-known MCDM methods. Four alternative methods for water allocation and four alternative options for drinking water supplying have been considered. These options are defined in regards to Pardis City in the vicinity of Tehran metropolitan in Iran.

In this city, bottled water, tanker and emergency tanks, mobile water treatment and also the existent water system were selected as water ration alternatives. Using existent wells and storage tanks, well drilling, and hand dug drilling were chosen for water supply alternatives. In conclusion, in minor damage scenario, for water ration options, using the existent water system and in water supply options existent storage tanks were outranked as the first. In moderate damage scenario, for water ration options using mobile water treatment and in water supply options existent storage tanks were outranked as the first. Also, in extensive and complete damage scenario, for water ration options using mobile water treatment and in water supply options well drilling were outranked first among other alternatives in emergency conditions.

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